Reefscaper

Project Summary

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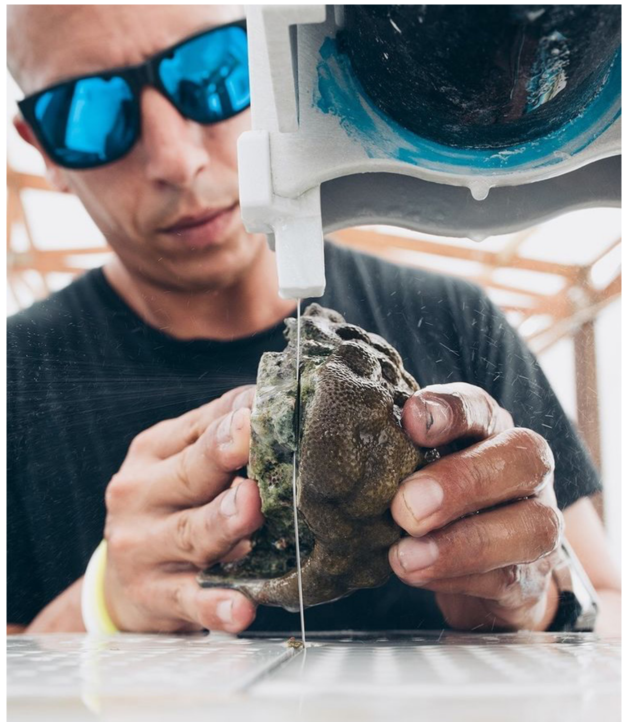
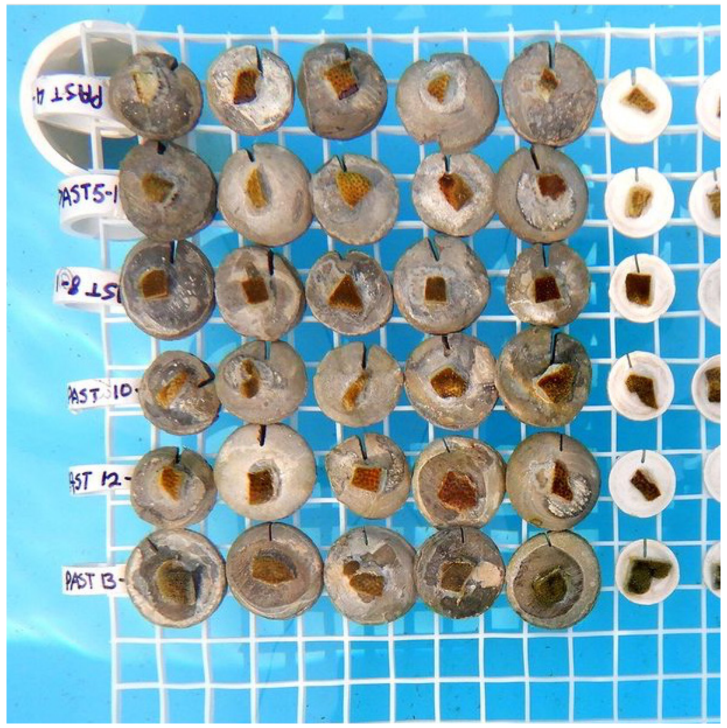
problem

Coral reefs are the most diverse ecosystems on the planet. They support over 25% of marine species despite covering less than 1% of the ocean floor. They offer many benefits including the natural protection of coastlines by dissipating up to 97% of wave energy and promising treatments in the medical field. Additionally, according to a 2017 study, coral reef tourism generates an estimated $36 billion in revenue each year. *

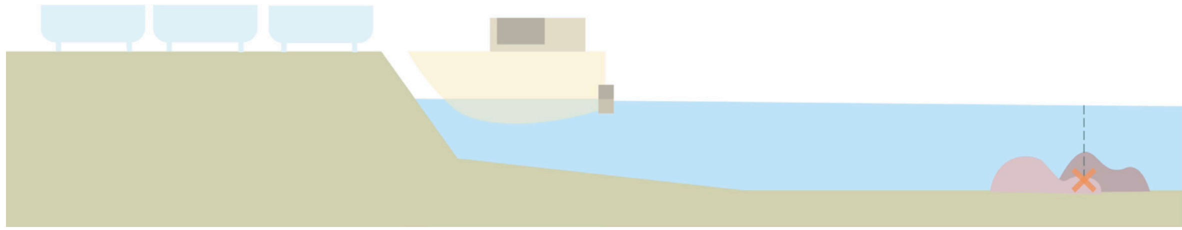
However, pollution, ocean warming and over exposure to sunlight have led to mass coral bleaching events. In the last 40 years nearly half of the world's reefs have died and, according to trends, all may be dead by 2050.

Microfragmentation is a relatively new restoration technique that involves cutting up coral into tiny pieces, stimulating rapid healing and resulting in them growing up to 40 times faster than they would in the wild. The separate coral pieces can then fuse and form sizes of coral in 2 years that would've previously taken 100 years. Once the microfragmented coral pieces have had time to mature in a nursery they are then "outplanted" back onto the reef by divers and secured using various methods.





* https://reef-world.org/blog/no-coral-reefs



Microfragmentation process stages

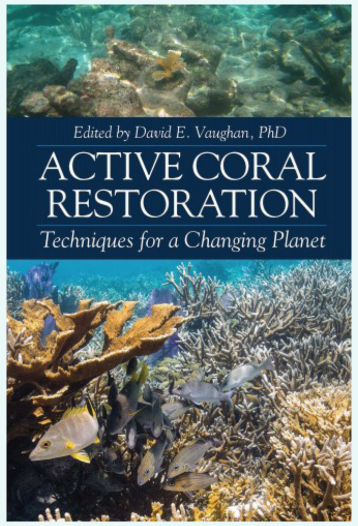
Collect donor corals → Cut donor corals into microfragments (approx. 1 cm) & mount onto substrates → Grow microfragments in nursery → Outplant microfragments → Monitor outplants

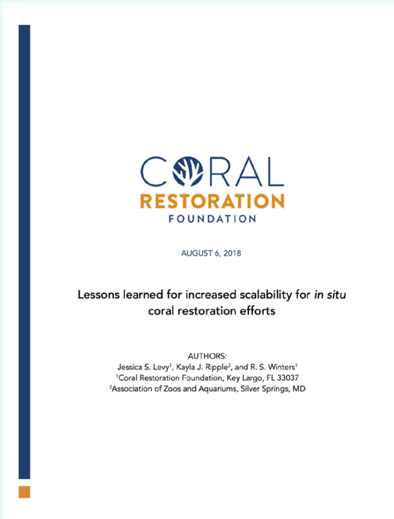
Unfortunately, the current methods that divers undertake to outplant the microfragmented coral onto the reefs are crude - making it the most time consuming and labour intensive stage of the process. Due to this, organisations are significantly limited by boat hire fees, diver wages and SCUBA equipment costs. Consequently, the current methods lack the ability to be carried out at a large scale - which is essential in order to match the scale of threats that are occurring.

Therefore, there was scope for a product to help speed up and streamline the outplanting process - allowing it to be employed at a larger scale.

Outplanting problems

Labour intensive | *Expensive* | *Time consuming* | *SCUBA equipment limitations* | *Difficult to upscale*





Scientific articles, white papers and textbooks were crucial to help fully understand the restoration process. Additionally, contact was made early in the project with potential product users and professionals in the field. This involved video calls and email exchanges with restoration specialists and scientists from several organisations - including Seascape Caribbean, Perry Institute of Marine Science and Coral Vita. Valuable insights were gained that helped to direct the iterative design process.

"Outplant capacity is the rate limiting factor for restoration - limited capacity to move corals to reef sites quickly and efficiency." - Coral Restoration Foundation (CRF)

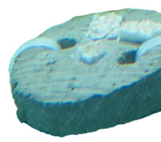
"Methods require one diver to secure one coral at a time. This scale is too small to achieve large scale goals for reef recovery." - CRF

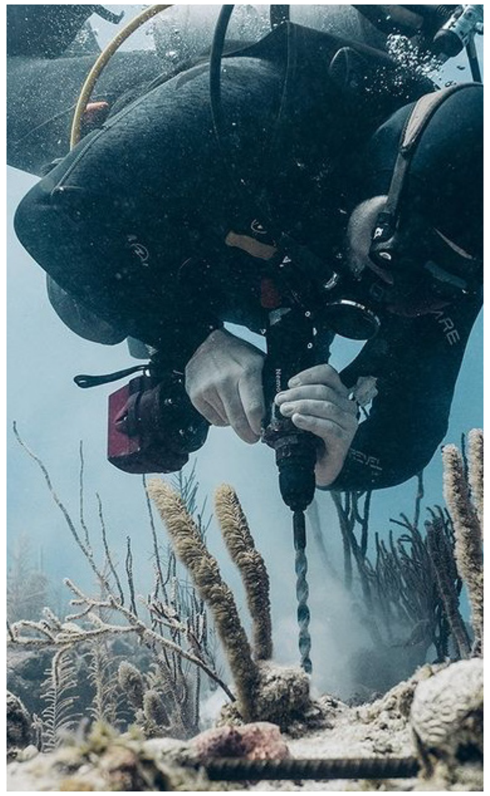
Current methods

Plug

Cookie

Puck





Current methods employed to outplant corals vary incredibly between organisations. The most common techniques involve a substrate "plug" (containing a stem form) that is slotted and glued into holes that are drilled into the dead reef or groups of plugs are glued into larger coral "cookies" (larger cement structures) that are secured onto the reef using screws or cement. At times "puck" substrates are used which are flat cement disk-shaped forms that are glued flat to the reef.

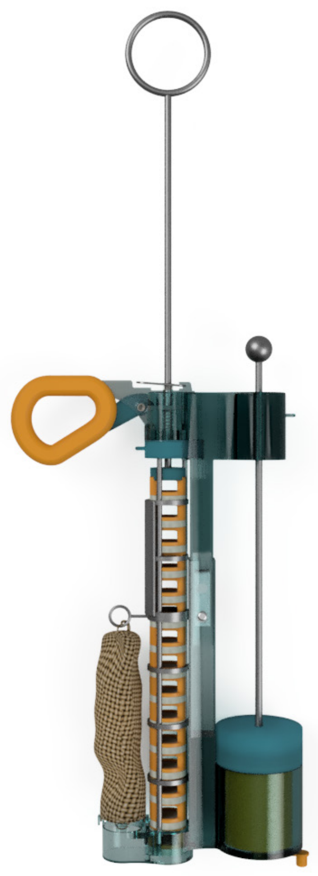
The corals and cookies are transported on egg crates and plastic trays. If cement adhesive is used, it is most commonly applied using an icing bag method. Otherwise, marine epoxy is used or an underwater drill and screws.

After exploring the various methods in depth it was decided to focus the concept on planting individual coral fragments (rather than in groups like the cookie method) as it is easier to handle and consequently encounters less difficulties with attachment. Smaller, more manageable sized corals also allows for modularity and customisation when it comes to the arrangement of the outplants on the reef - ultimately enabling the product to suit more variations in restoration reef sites.

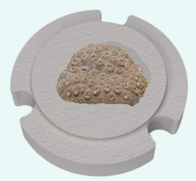
The "coral cookie" method was chosen to be the main point of comparison against the Reefscaper concept as it is the most up-to-date method used by the most notable restoration organisations at this moment.

product overview

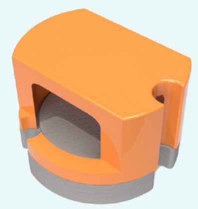
Reefscaper



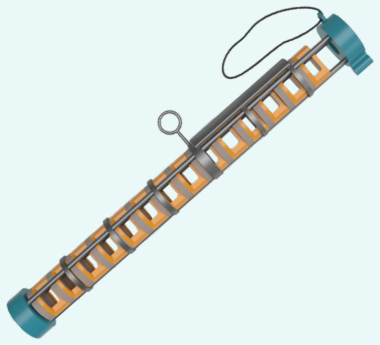
What	*Hand-held device to streamline the outplanting process for divers through easier coral transport, deployment & cement adhesive application*
Who	*Restoration divers*
Why	*The current methods used to outplant coral microfragments are crude, time consuming, labour intensive, expensive and unable to be employed at scale*
Where	*Coral land-based nurseries & tropical coral reef environments (approx. 10 metre depth)*
How	*Based on a caulking-gun mechanism in which a manual trigger handle transfers force to a plunger rod through the use of a spring & an actuator plate. The plunger forces the stacked corals vertically along a 3-rod track where they exit at the base of the cartridge. Adhesive barrel includes a separate, simple plunging mechanism.*



Cement substrate pucks for the coral microfragments to grow upon and that can easily be stacked into the cartridges.

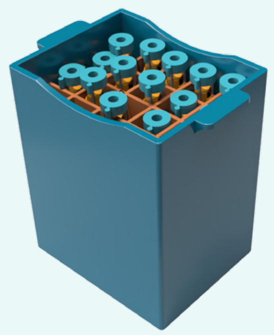


Spacer design that ensures coral safety during transport and is conveniently gathered in the spacer collection bag during deployment.

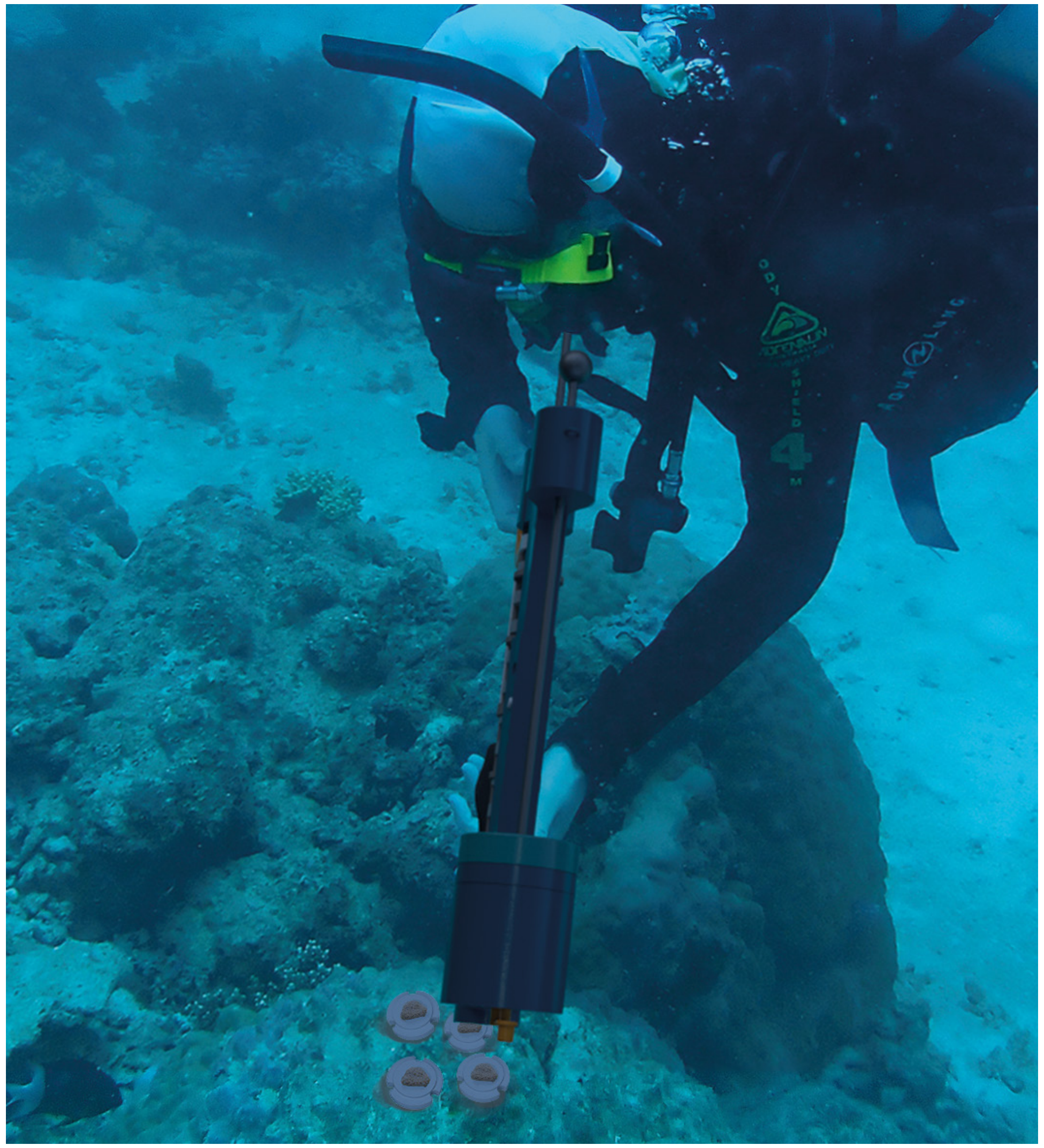


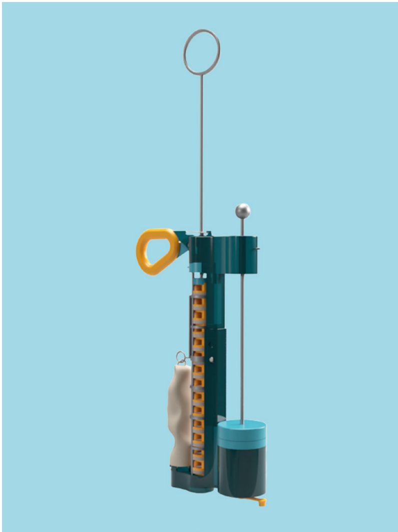
Replaceable cartridges that fit into the gun for efficient turnover and up-scaling of the process. Each cartridge contains 16 coral microfragments.

Reusable silicone pouch for easy handling of cement adhesive and a simple cleaning process.

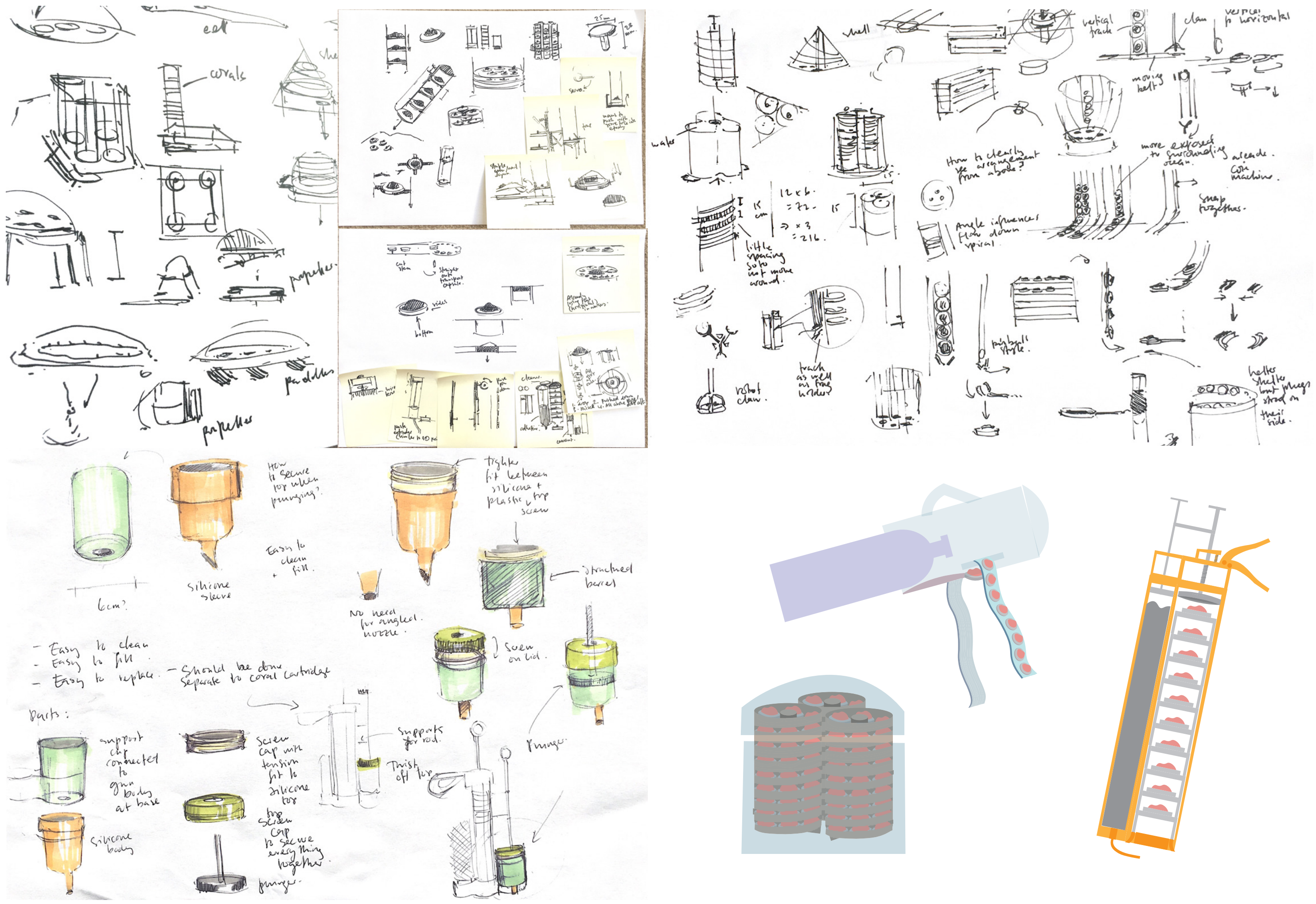


Transport box able to carry up to 20 coral cartridges (320 corals) and contains a convenient curved top surface for gun placement while not in use underwater.

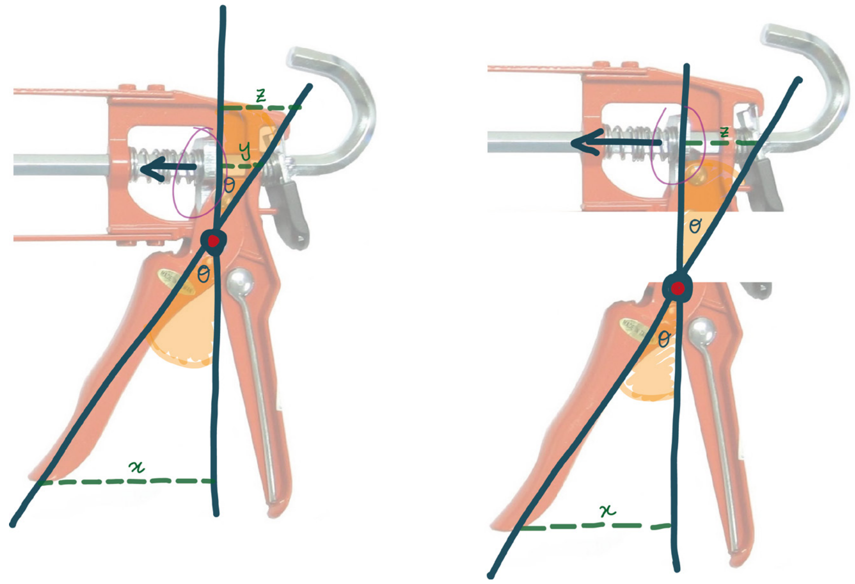




Concept generation



Coral deployment



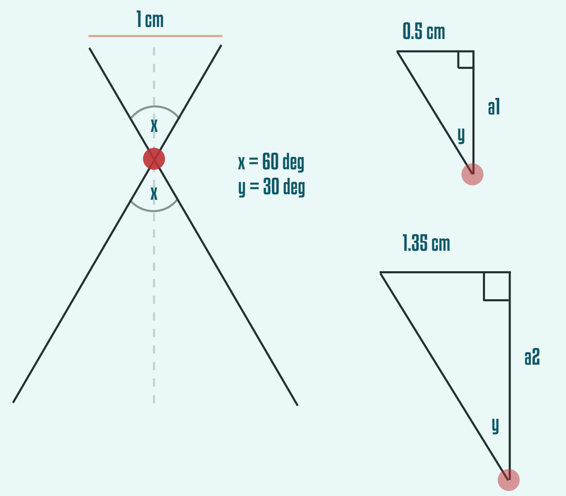
The design of the deployment mechanism started with an exploration into other industries including food production, aquaponics, agriculture and construction to find mechanisms carrying out similar functions that could be adapted to suit the coral farming process.

The caulking gun design from the construction industry stood out due to its effective and simple way of applying mechanical force. Additionally, its long length allows for stacking of corals. Similar to the replacing of silicone tubes, cartridges of corals could act as both the transport case and help to position the coral for attachment.

Iterative prototyping

Once the product and user requirements were established through research and speaking to people in the field, concepts were generated.

Prototype iterations were made throughout the project. They started in the form of cardboard and, later in the development stages, were in the form of 3D prints.



Original distance:

tan(30) = 0.5/a1
a1 = 0.5/tan(30) = 0.866cm

Required distance:

Want a plunging distance of 2.7cm to equal the height of the coral puck/spacer pair so that only one coral is deployed at a time.

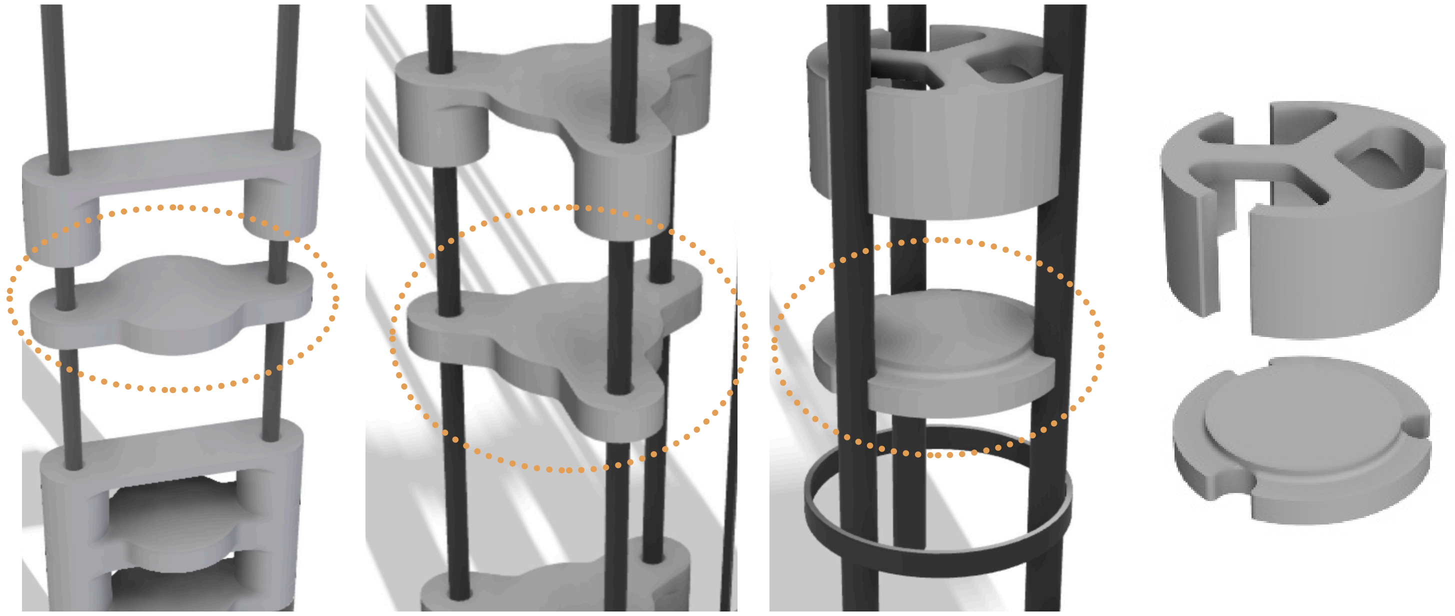
2.7/2 = 1.35cm
a2 = 1.35/tan(30) = 2.338cm = 2.4cm approx.

Actuator plate/plunger rod mechanism needs to be 2.4cm away from the pivot point.

Key calculations were carried out to suit the design of the caulking gun to my application - including altering the distance the plunger moves per trigger application so that only a single coral is deployed at a time.

Substrate design

During coral restoration coral fragments are almost always mounted on a substrate to promote growth and make handling and arrangement in the nursery easier. This form can vary in shape, size and material. As stated earlier, it is commonly found in the form of a "plug" but this does not always have to be the case.



Various substrate designs were explored using CAD. The substrate designs were specialised to fit within the cartridge design and considerations were made to avoid corners and crevices so that algae would not settle. This would require less maintenance and cleaning as the algae must be removed to prevent it from threatening the coral. The final design was chosen due to lower risks of breakage and the ability to include support rings around the 3 rods of the cartridge for added strength.

The chosen substrate design is referred to as a "puck" throughout the project due to its similarity in appearance to other existing puck substrate designs (which bear similarity to a hockey puck).

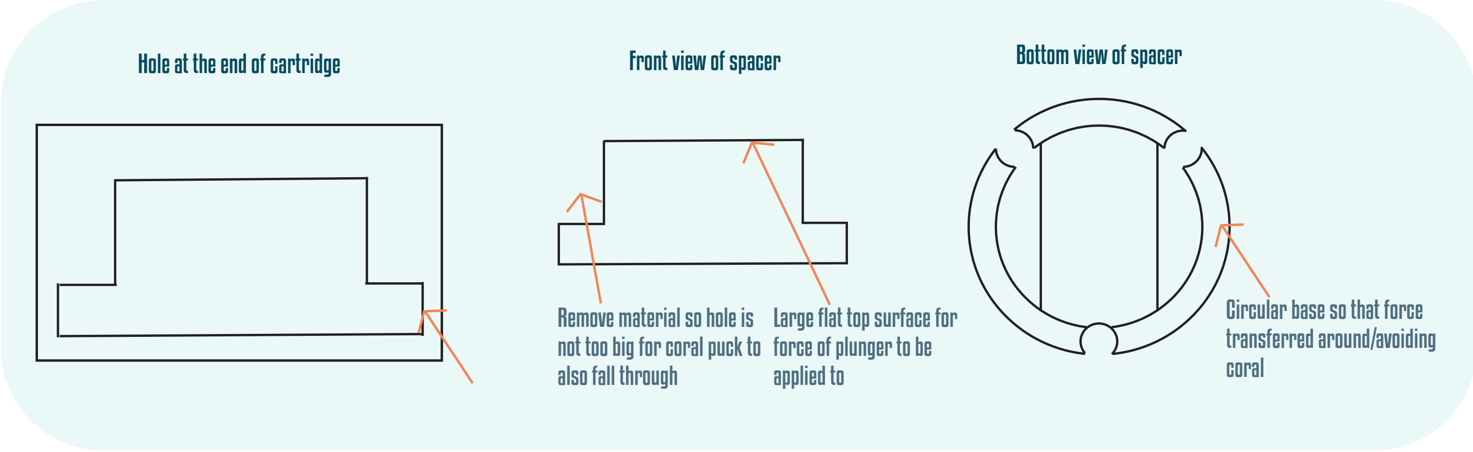
The puck design was designed to be made from cement as it is easily accessible and widely accepted as a suitable material for coral to grow upon.

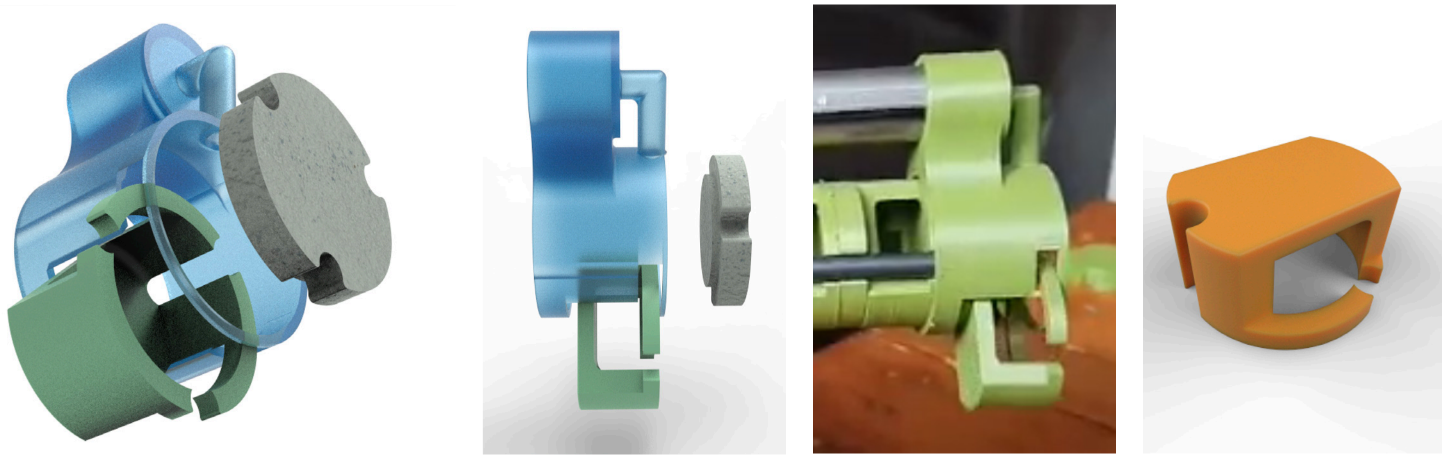
Spacer design

It was established that the coral would need a protection design while stacked in the cartridges, to ensure that no force was being applied to the top surface of the puck where the coral was located.

Several spacer concepts were explored including, biodegradable spacers that wouldn't require collection once exiting the device, spacer pins or legs that protrude from the puck substrate itself or reusable spacers that could be easily collected after use.

Evaluation and user feedback led to the decision of a reusable spacer that exits the end of the cartridge through a gap designed to allow the spacer to fit but not the coral pucks.



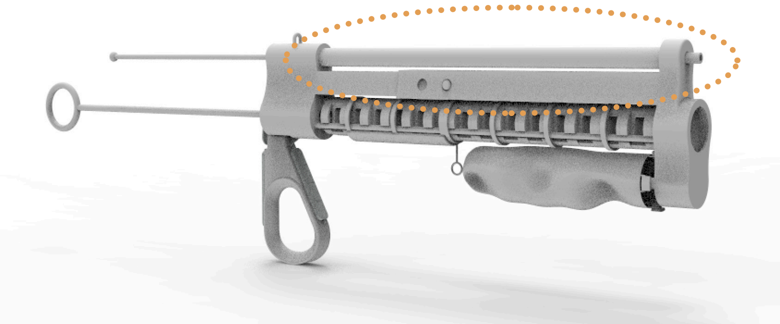


A unique spacer form was developed and tested. It stacked smoothly into the cartridge, successfully kept the corals safe and separated and eventually fell through a tailored hole at the end of the gun (into a collection bag).

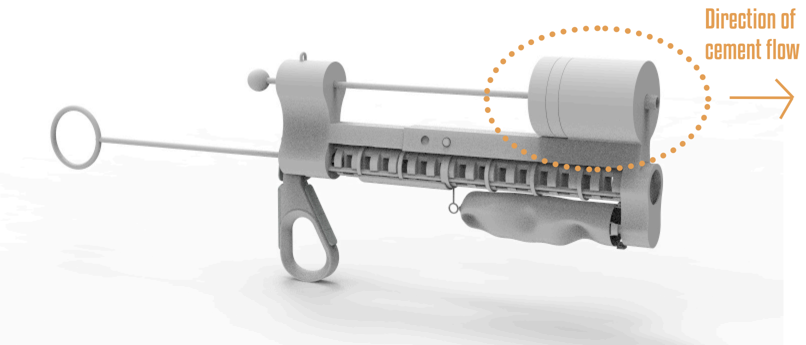
development 3

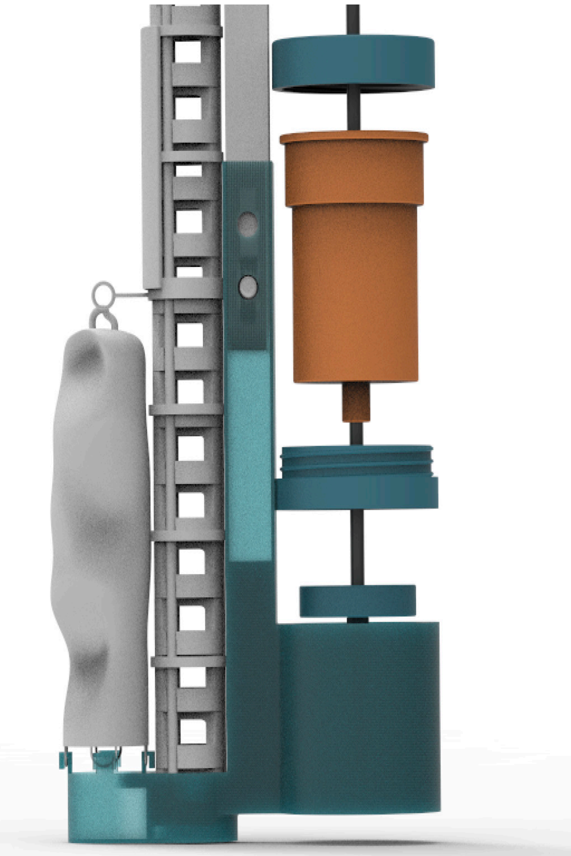
Adhesive deployment

Old design



New design



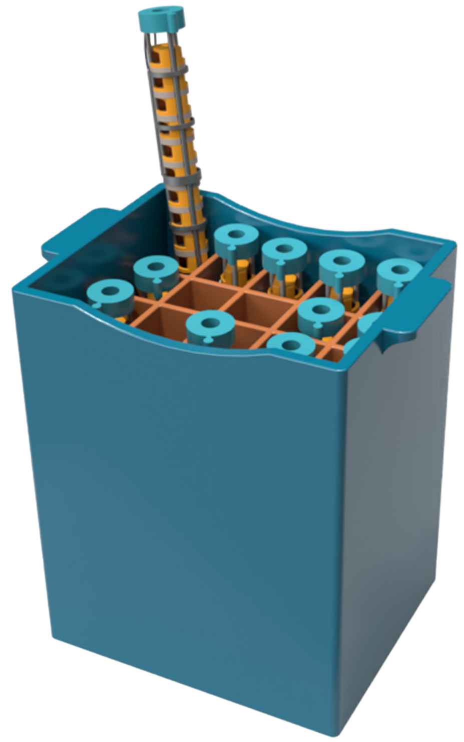


Various methods for applying the adhesive to the reef were tested.

Initially the concept included a joint plunger mechanism for the corals and the adhesive. For simplicity, easier maintenance and reduced complexity when it came to timing the exit of both the coral and cement, the plunger mechanisms were separated.

Changes were made to the design to reduce the mess involved with handling the cement, improve the adhesive barrel cleaning process and limit the surface area of the adhesive barrel to reduce cement cure time .

Transport



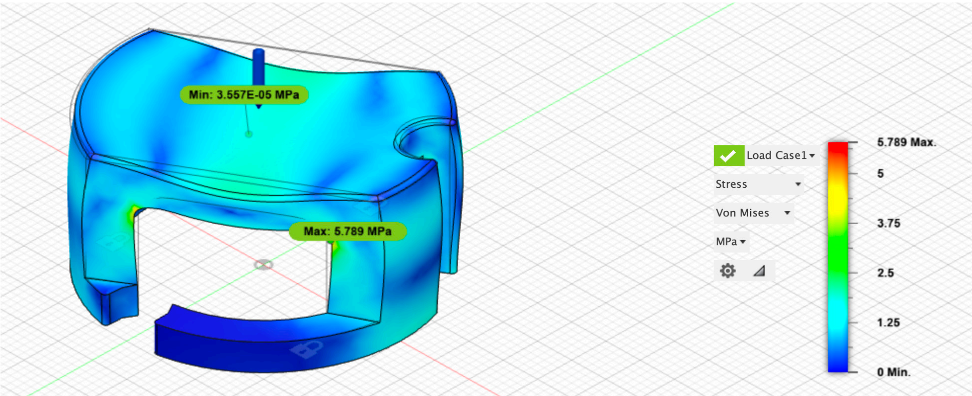
Box dimensions (cm)	Coral cartridges carried	Coral microfragments carried
28 x 28	4 x 4 = 16	16 x 16 = 256
28 x 35	4 x 5 = 20	16 x 20 = 320
35 x 35	5 x 5 = 25	16 x 25 = 400
35 x 42	5 x 6 = 30	16 x 30 = 480
42 x 42	6 x 6 = 36	16 x 36 = 576

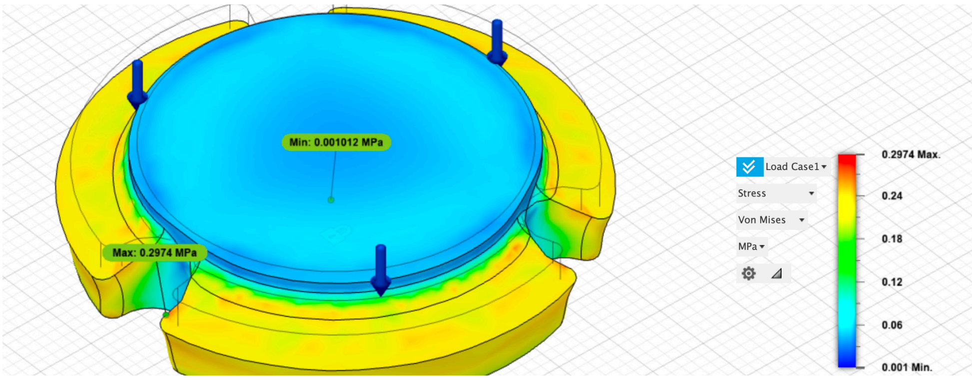
A concept for a transport box was designed. Comparisons were made to figure out the optimal size for the transport box.

A transport box measuring 28 x 35 x 45 cm in size was designed to more easily handle and transport up to 320 corals in one journey. A grid, inspired by the design of wine boxes, was incorporated into the box to reduce the risk of collisions between the cartridges and is removable to make cleaning the box easier.

development 4

Static force tests & comparing power methods





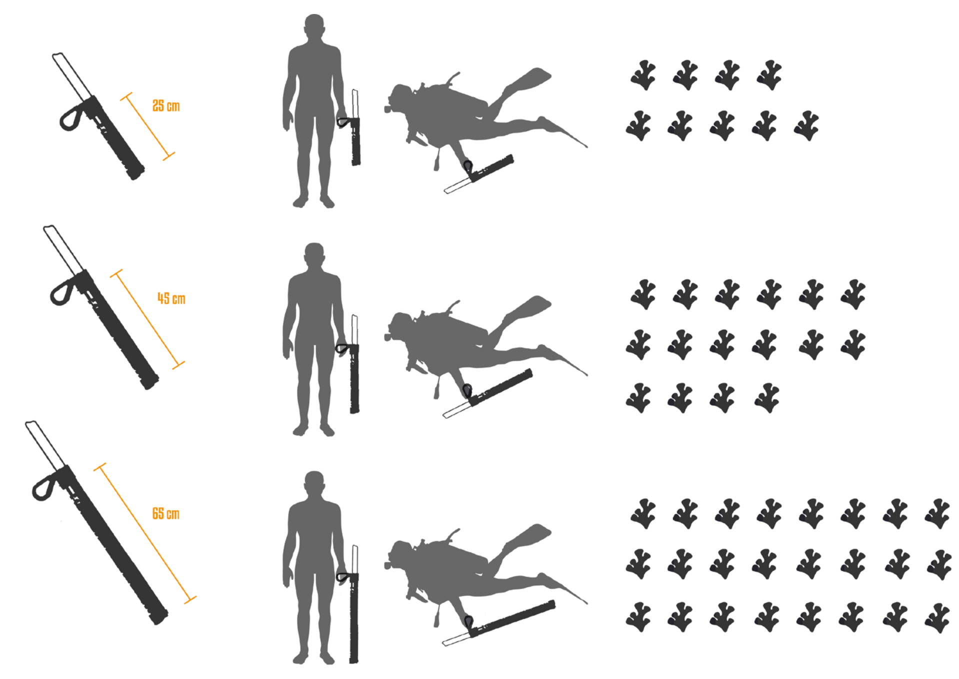
The thrust ratio of a caulking gun corresponds to the ratio in the amount of force the user applies to the trigger handle versus the amount of force which is then applied by the plunger head.

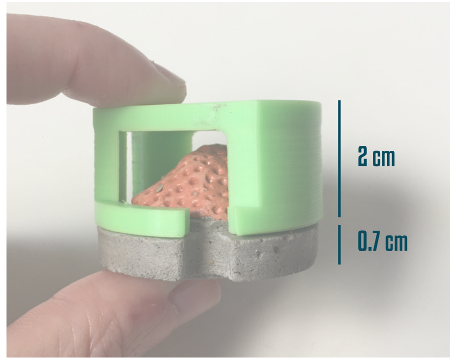
By measuring the force required to decompress the trigger handle of the caulking gun a full distance, and factoring in the thrust ratio of 10:1, the force exerted by the plunger head onto the coral spacers and pucks was calculated.

This allowed static force simulations to be carried out to check if the strength of the spacer and puck designs were sufficient in strength.

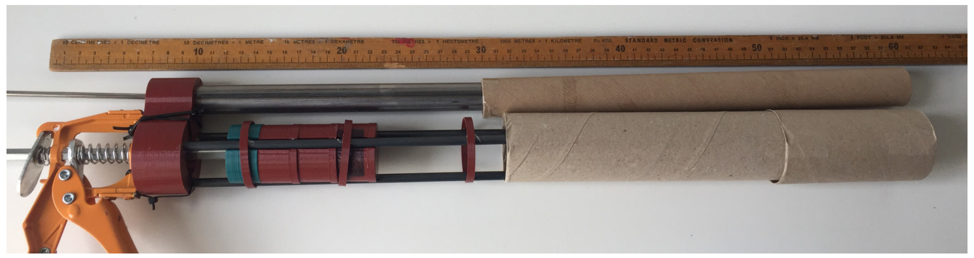
Additionally, power methods were compared - including electrical, mechanical and pneumatic. Calculations were carried out, based on the values for comparable construction tools, which proved that there was no need for the gun to be pneumatically or electrically powered. Instead, manual force exerted by the diver would be sufficient to power the Reefscaper gun.

Cartridge length calculations



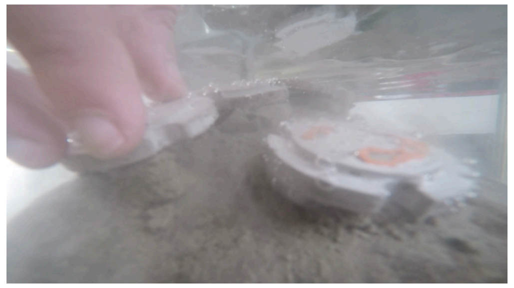


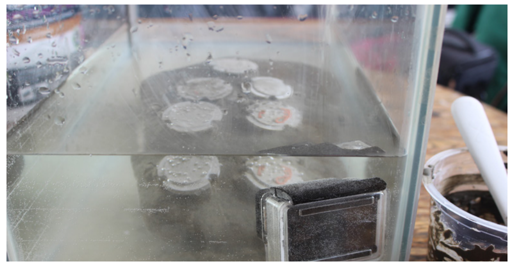
Length of gun (cm)	Number of corals carried	Amount of cartridges required to reach goal of 300 corals
25	9	34
35	12	25
45	16	19
55	20	15
65	24	13



Calculations were done to establish the optimum length for the coral cartridges. This took into account ease of handling for the diver as well as the quantity of corals carried. Cardboard tubes were attached to the end of the prototype to model the various lengths at scale

Underwater testing





Testing of the final prototype was carried out in an aquarium tank and an aquatic environment. This helped to validate certain aspects of the design (including the adhesive application & spacer collection method) and gain further insights into the coral attachment process.

user journey

1. Mount coral microfragments on puck substrates & grow in nursery until matured

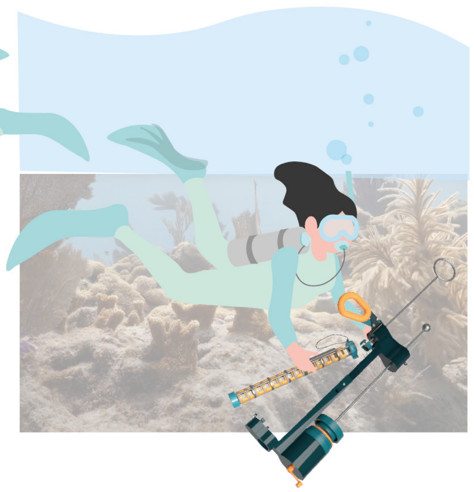
2. Stack the corals & spacers (for safety) into the cartridges

3. Load the cartridges into the transport box

4. Move the transport box, Reefscaper gun & cement adhesive onto boat

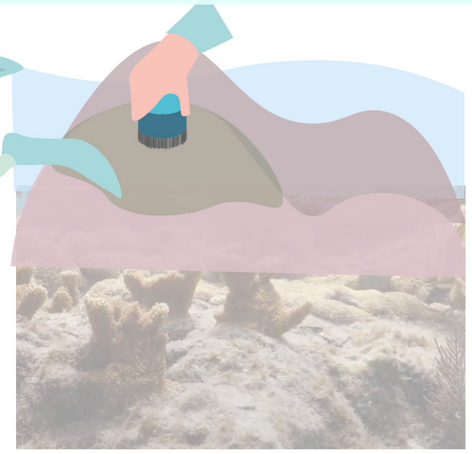
5. Once at the outplant site, carry the items to the seafloor

6. Using the push lock mechanism load a coral cartridge into the Reefscaper gun

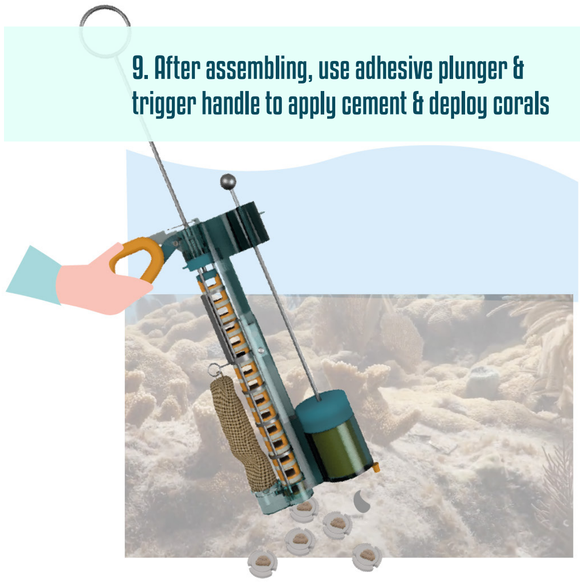


7. Rest the gun on the box & using the plunger end ring for support, fill the adhesive pouch

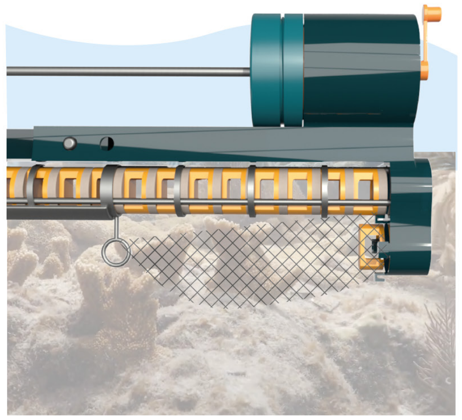
8. Clean the dead reef of any algae to improve attachment



9. After assembling, use adhesive plunger & trigger handle to apply cement & deploy corals

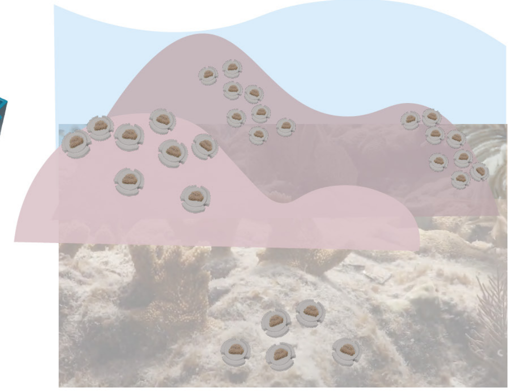


10. Position the gun to allow for the spacers to fall into the collection bag after each application



11. Once empty, the cartridge can be replaced by another in the transport box

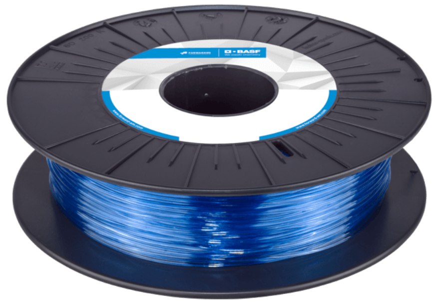
12. Area of dead reef surface is covered with coral that will eventually fuse to "reskin" the reef



Current situation

Reefscaper concept

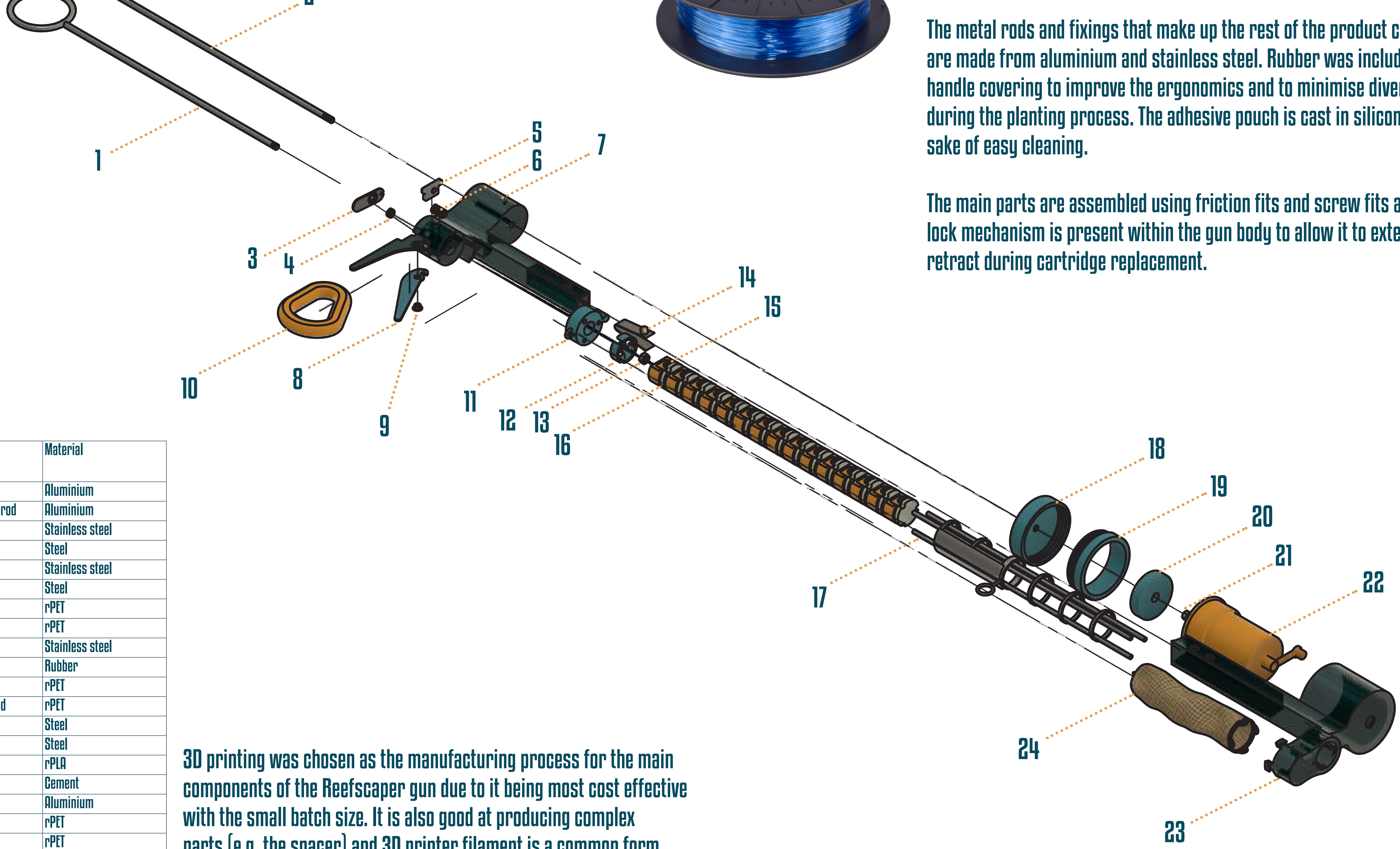
materials, manufacture & assembly



Using the Granta EduPack material database software, limits were added to narrow down the suitable materials and recycled PET plastic (rPET) was chosen as the main material for the body of the Reefscaper gun.

The metal rods and fixings that make up the rest of the product components are made from aluminium and stainless steel. Rubber was included as a handle covering to improve the ergonomics and to minimise diver fatigue during the planting process. The adhesive pouch is cast in silicone for the sake of easy cleaning.

The main parts are assembled using friction fits and screw fits and a push lock mechanism is present within the gun body to allow it to extend and retract during cartridge replacement.



Part no.	Quantity	Part name	Material
1	1	Coral plunger rod	Aluminium
2	1	Adhesive plunger rod	Aluminium
3	1	Release plate	Stainless steel
4	1	Small spring	Steel
5	1	Actuator plate	Stainless steel
6	1	Big spring	Steel
7	1	Gun body top	rPET
8	1	Trigger handle	rPET
9	1	Rivet	Stainless steel
10	1	Handle cover	Rubber
11	1	Cartridge cap	rPET
12	1	Coral plunger head	rPET
13	1	Hex nut 1	Steel
14	1	Push lock	Steel
15	16	Spacer	rPLA
16	16	Coral puck	Cement
17	1	Cartridge rack	Aluminium
18	1	Twist cap top	rPET
19	1	Twist cap bottom	rPET
20	1	Adhesive plunger head	rPET
21	1	Hex nut 2	Stainless steel
22	1	Adhesive pouch	Silicone
23	1	Gun body end	rPET
24	1	Spacer collection net	Upcycled fishing net

3D printing was chosen as the manufacturing process for the main components of the Reefscaper gun due to it being most cost effective with the small batch size. It is also good at producing complex parts (e.g. the spacer) and 3D printer filament is a common form to source the materials of recycled PET and recyclyed PLA in. 3D printing, being a form of additive manufacture, produces minimal waste, staying in line with the sustainable ethos of the product.